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Modulus of Elasticity and Poisson's Ratio for Types 17-4 PH and 410 Stainless Steels in Compression

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U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Manufacturing Engineering Laboratory
Gaithersburg, MD 20899

Prepared for
Liberty Technologies
Lee Park
555 North Lane
Conshohocken, PA 19428-2208

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
John W. Lyons, Director

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Robert A. Mosbacher, Secretary
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Abstract

Values of the modulus of elasticity and Poisson's ratio in compression were determined for three samples of type 17-4 PH stainless steel and for one sample of type 410 stainless steel. The three samples of the 17-4 PH were from different locations of one bar of material. The results obtained agree well with values reported in the literature.

Introduction

As requested by Liberty Technologies, the NIST Mechanical Properties and Performance Group determined the modulus of elasticity (E) and Poisson's ratio (ν), both in compression, for samples of types 17-4 PH and 410 stainless steels that were supplied by the company.

Specimen Preparation

The 17-4 PH stainless steel was supplied in the form of a cylindrical bar 4.13 cm (1 5/8 inches) in diameter and 114.3 cm (45 inches) long. Three cylindrical specimens, nominally 3.81 cm (1.5 inches) long and 1.27 cm (0.5 inch) in diameter, were machined by the NIST Fabrication Technology Division from this bar. One specimen was taken from each end of the bar and one was taken from the center (measured lengthwise) as shown in figure 1. The longitudinal axes of all three specimens were coincident with the longitudinal axis of the bar. The specimens were designated A, B-C, and D, as shown in figure 1. The two bar lengths between the specimens were designated A-B and C-D. These designations were given to the component ends as shown in the figure so that the component position and orientation within the bar could be maintained.

These specimens were prepared by first removing slightly oversize cylinders from the bar by electrical discharge machining (EDM). Machining of the cylinder surface was completed by centerless grinding to an 8 to 16 microinch finish. The ends of each specimen were ground flat and parallel to within 0.00025 cm (0.0001 inch).

Two machined specimens each of 410 and 416 stainless steel were also received from Liberty Technologies. These specimens were nominally 3.81 cm (1.5 inches) long and 1.27 cm (0.5 inch) in diameter when received. The ends were machined flat and parallel to within 0.00025 cm (0.0001 inch) at NIST in the same manner as the specimens of 17-4 PH.

Test Procedure

The three 17-4 PH specimens and one of the 410 specimens were tested. The second 410 specimen and neither of the 416 specimens were tested in accordance with instructions from Liberty Technologies. Both E and ν were determined by testing the specimens in compression using an Instron universal testing machine, model

no. TTCML, serial no. 1598. The load applied to the specimen during testing was measured with a load cell. The load cell was calibrated against a 4535.9 kg (10,000 lb) capacity Morehouse proving ring, number 80, that itself had been calibrated and certified by the NIST Force Measurements Group. A copy of the Report of Force Calibration for the proving ring is attached as Appendix A.

The initial length and diameter of specimens tested were determined to the nearest 0.00025 cm (0.0001 inch). Axial and diametral displacements of the specimens during load application were measured with extensometers. The axial extensometer was MTS model no. 632.11B-20, serial no. 925. The diametral extensometer was MTS model 632.19B-20, serial no. 238. Both extensometers were calibrated with a micrometer head which could be read to the nearest 0.000025 cm (0.00001 inch). This micrometer head was calibrated by the NIST Calibration Services Group. The certificate of test is given in Appendix B.

Both the modulus of elasticity and Poisson's ratio must be determined from elastic changes in the dimensions of the specimen when it is under load. In order to make several tests or runs on any given specimen, it was important not to stress the specimen to the point of yield. Because of the general relationship between hardness and strength, Rockwell C hardness measurements were made on two of the 17-4 PH specimens and Rockwell 30T measurements were made on the 410 specimen to determine the approximate strengths of the materials. The results of these measurements are given in Table 1. The hardness of the 17-4 PH stainless steel suggests that this material is in either the annealed condition or has been given a H1150 temper[1,2] and would be expected to have a tensile strength of approximately 793 to 1034 MPa (115 to 150 ksi) and a yield strength of about 517 to 758 MPa (75 to 110 ksi). The maximum loads applied to the 17-4 PH specimens and the 410 specimens were nominally 4545 kgf (10,000 lbf) and 2727 kgf (6000 lbf), respectively. These loads were well below the estimated yield strengths of the materials. All tests were run at a crosshead speed of 0.5 mm (0.02 in) per minute. A data acquisition system recorded outputs from the load cell and the extensometers at a rate of 5 times per second.

Test Results

The values for the modulus of elasticity, Poisson's ratio, and E/v for three specimens from the bar of 17-4 PH stainless steel and for one of the 410 stainless steel specimens are presented in Table 2. The values given in the table are averages based on the results of a number of runs for each specimen. A representative plot of axial and diametral displacement versus load for 17-4 PH specimen A is shown in figure 2. Similarly, a representative plot of axial and diametral displacement versus load for the 410 stainless steel specimen is shown in figure 3.

Values for the modulus of elasticity reported in the literature[3]

are 193 GPa (28 x 10^6 psi) for 17-4 PH stainless steel and 221 GPa (32 x 10^6) for 410 stainless steel. Values reported for Poisson's ratio[1] are .291 for the 17-4 PH stainless and .27-.29 for the 410 material. The experimental values reported here compare well with the literature values.

References

1. Structural Alloys Handbook, Volume 2, Battelle Columbus Division, 1987, Wrought Stainless Steel Selector Chart, pp. 4-7; 410 Stainless Steel, pp. 2, 12; 17-4 PH and 15-5 PH Stainless Steel, pp. 16-17.

2. Metals Handbook, 9th edition, Volume 3, American Society for Metals, 1980, pp 26, 29.

3. Handbook of Stainless Steels, Peckner, Donald, and Bernstein, I.M., McGraw-Hill, 1977, pp. 19-2, 19-3.

Table 1. Results of Hardness Measurements

Rockwell C Scale Measurements

	17-4 PH Specimen A	17-4 PH Specimen B-C
	29.3	29.9
	30.1	30.0
	29.8	30.3
	29.4	29.8
	28.5	29.7
Average	29.4	29.9

Rockwell 30T Scale Measurements

	410 Specimen
	76.8
	77.8
	75.8
Average	76.8

Table 2. Results of Modulus of Elasticity and Poisson's Ratio Measurements

17-4 PH stainless steel specimen A

Modulus of elasticity (E):	194 ± 0.48 GPa	(28.10 ± 0.07 x 10^6 psi)	[± 0.2%]
E/ν:	643 ± 6.89 GPa	(93.22 ± 1.00 x 10^6 psi)	[± 1.1%]
Poisson's ratio (ν):	0.3014 ± 0.0025	[± 0.8%]	

17-4 PH stainless steel specimen B-C

Modulus of elasticity (E):	192 ± 0.21 GPa	(27.80 ± 0.03 x 10^6 psi)	[± 0.1%]
E/ν:	637 ± 0.34 GPa	(92.32 ± 0.05 x 10^6 psi)	[± 0.1%]
Poisson's ratio (ν):	0.3011 ± 0.0001	[± 0.0%]	

17-4 PH stainless steel specimen D

Modulus of elasticity (E):	192 ± 0.21 GPa	(27.88 ± 0.03 x 10^6 psi)	[± 0.1%]
E/ν:	633 ± 3.65 GPa	(91.74 ± 0.53 x 10^6 psi)	[± 0.6%]
Poisson's ratio (ν):	0.3037 ± 0.0012	[± 0.4%]	

Average values for the 17-4 PH stainless steel rod

Modulus of elasticity (E):	193 ± 1.10 GPa	(27.92 ± 0.16 x 10^6 psi)	[± 0.6%]
E/ν:	637 ± 5.17 GPa	(92.43 ± 0.75 x 10^6 psi)	[± 0.8%]
Poisson's ratio (ν):	0.3021 ± 0.0014	[± 0.5%]	

410 stainless steel

Modulus of elasticity (E):	220 ± 1.45 GPa	(31.98 ± 0.21 x 10^6 psi)	[± 0.7%]
E/ν:	774 ± 17.0 GPa	(112.30 ± 2.46 x 10^6 psi)	[± 2.1%]
Poisson's ratio (ν)	0.2856 ± 0.0072	[± 2.5%]	

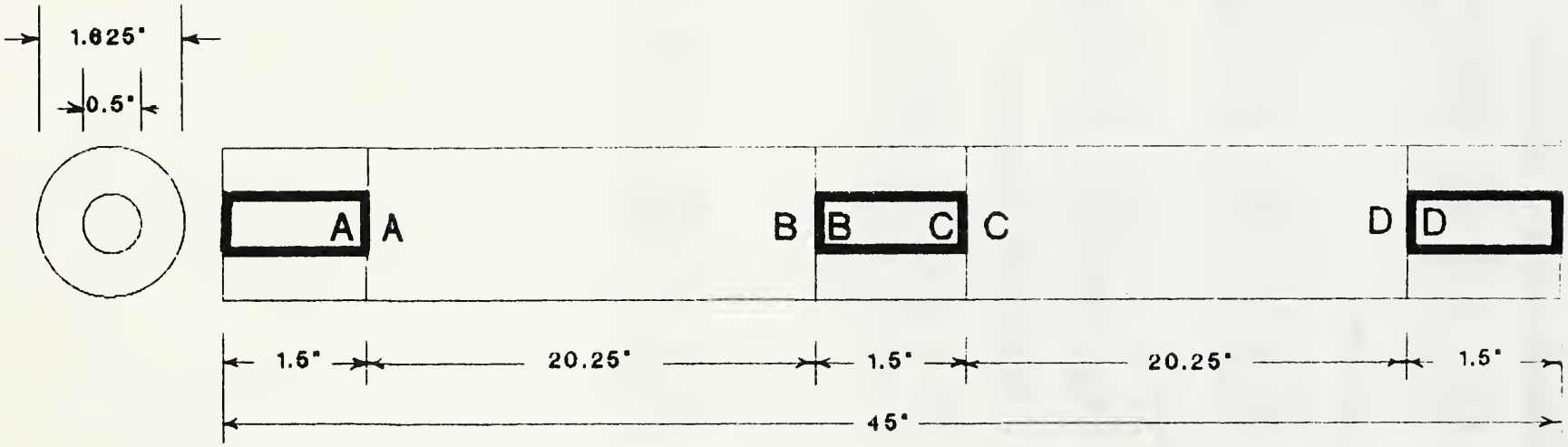


Figure 1. Schematic drawing of the bar of 17-4 PH stainless steel showing specimen locations. All dimensions in inches (1 in = 25.4 mm).

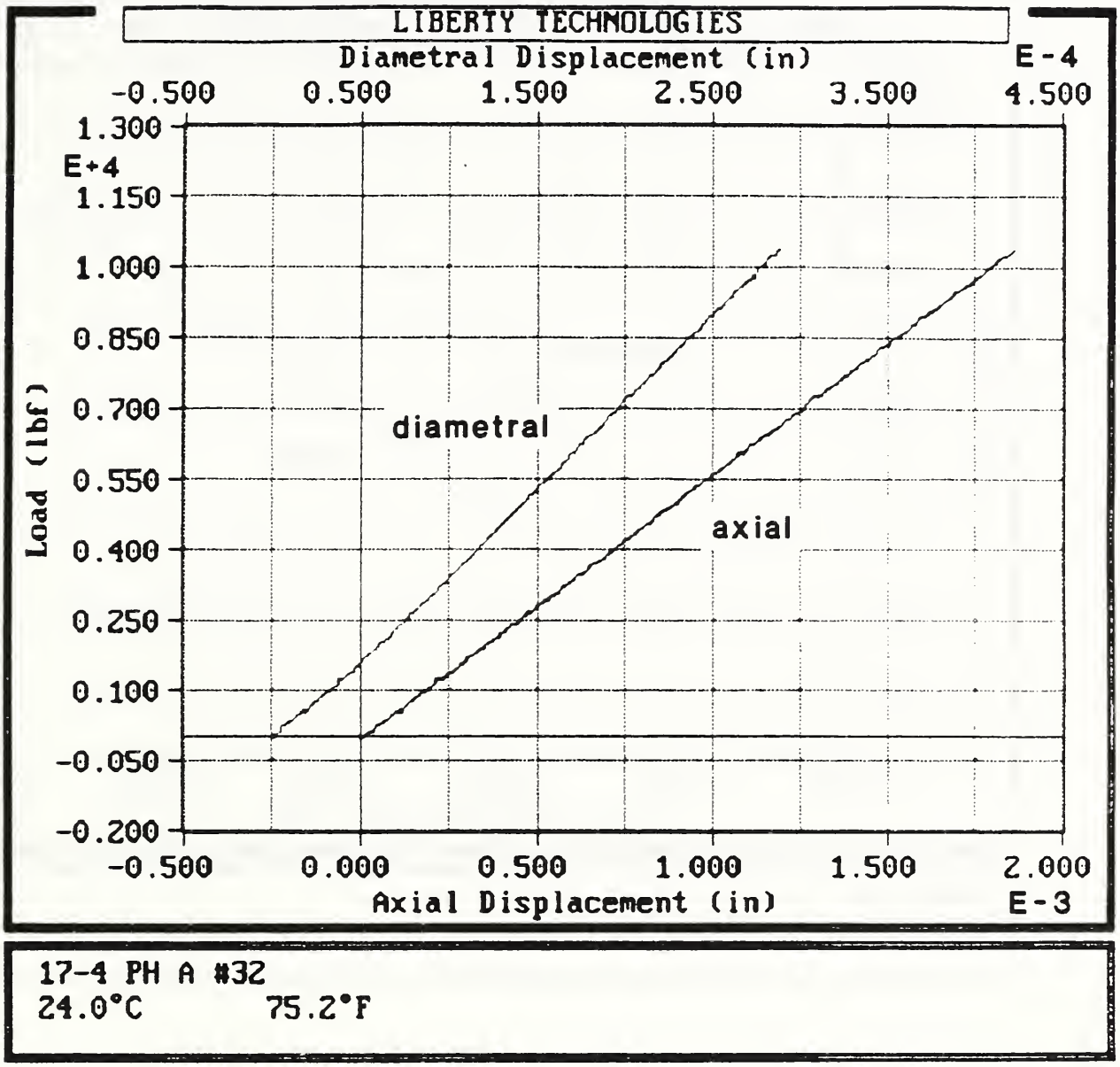


Figure 2. Representative plot of axial and diametral displacement versus load for specimen A from the bar of 17-4 PH stainless steel. Length dimensions are in inches (1 in = 25.4 mm). Load is in pounds force (1 lbf = 0.45359 kgf).

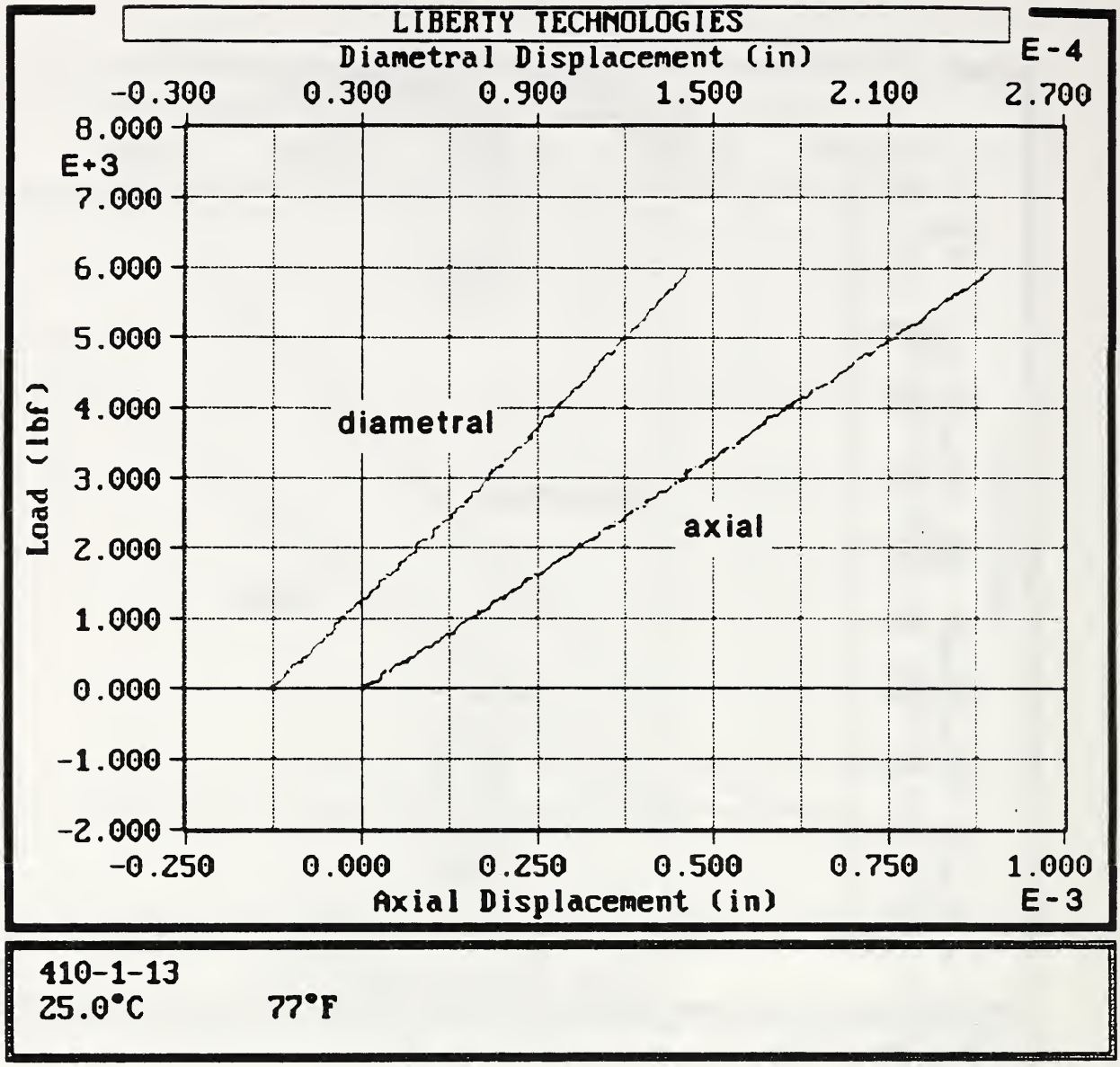


Figure 3. Representative plot of axial and diametral displacement versus load for the 410 stainless steel specimen. Length dimensions are in inches (1 in = 25.4 mm). Load is in pounds force (1 lbf = 0.45359 kgf).

Appendix A

Proving Ring No. 80 Calibration

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
(formerly NATIONAL BUREAU OF STANDARDS)
REPORT OF FORCE CALIBRATION

Test No. 822.07/910701
Calibration Date: July 1, 1991

Morehouse Proving Ring No. 80
Capacity 10000 lbf Compression

National Institute of Standards and Technology
Gaithersburg, Maryland

Purchase Order: 855-4643
Dated: May 28, 1991

The above force measuring device was calibrated in accordance with ASTM E74-83, "Standard Practices of Calibration of Force Measuring Instruments for Verifying the Load Indication of Testing Machines". The attached calibration data applies only when this device is used in a manner consistent with those procedures.

Calibration loads were applied by dead weights. Errors in the applied loads due to uncertainties in the adjustment of the weights and variations in air density did not exceed 0.002 percent.

The calibration data for a temperature of 23 degrees Celsius with analysis are enclosed.

Note: This is a report of a force calibration. To use this device for measuring mass, the effects of local gravity and air buoyancy must be taken into account.

For the Director,
National Institute of Standards and Technology

Donald S. Blomquist, Chief
Automated Production Technology Division
Manufacturing Engineering Laboratory

Enclosures

Calibration Date: July 1, 1991

Morehouse Proving Ring No. 80
Capacity 10000 lbf Compression

Compression Data for 23 Degrees Celsius

Applied Load (lbf)	Response Run 1	Response Run 2	Predicted Response	Change from Previous Calibration
700	56.58	56.75	56.70	0.01
1100	89.05	89.15	89.12	-0.01
1900	154.20	154.25	154.13	-0.04
2300	186.70	186.80	186.72	-0.06
3100	252.00	252.10	252.07	-0.09
3900	317.65	317.70	317.65	-0.10
4700	383.35	383.45	383.46	-0.12
5500	449.35	449.50	449.49	-0.12
6000	490.90	490.85	490.87	-0.12
6500	532.42	532.27	532.35	-0.12
7000	574.05	573.75	573.91	-0.11
8000	657.20	657.25	657.29	-0.10
8500	699.30	699.20	699.12	-0.08
9000	741.15	741.13	741.04	-0.07
10000	825.00	825.05	825.13	-0.03

The coefficients of the following equation were fitted to the calibration data using the method of least squares. Units for response and load are the same as shown in the above table.

$$\text{Response} = A + B(\text{load}) + C(\text{load})^2,$$

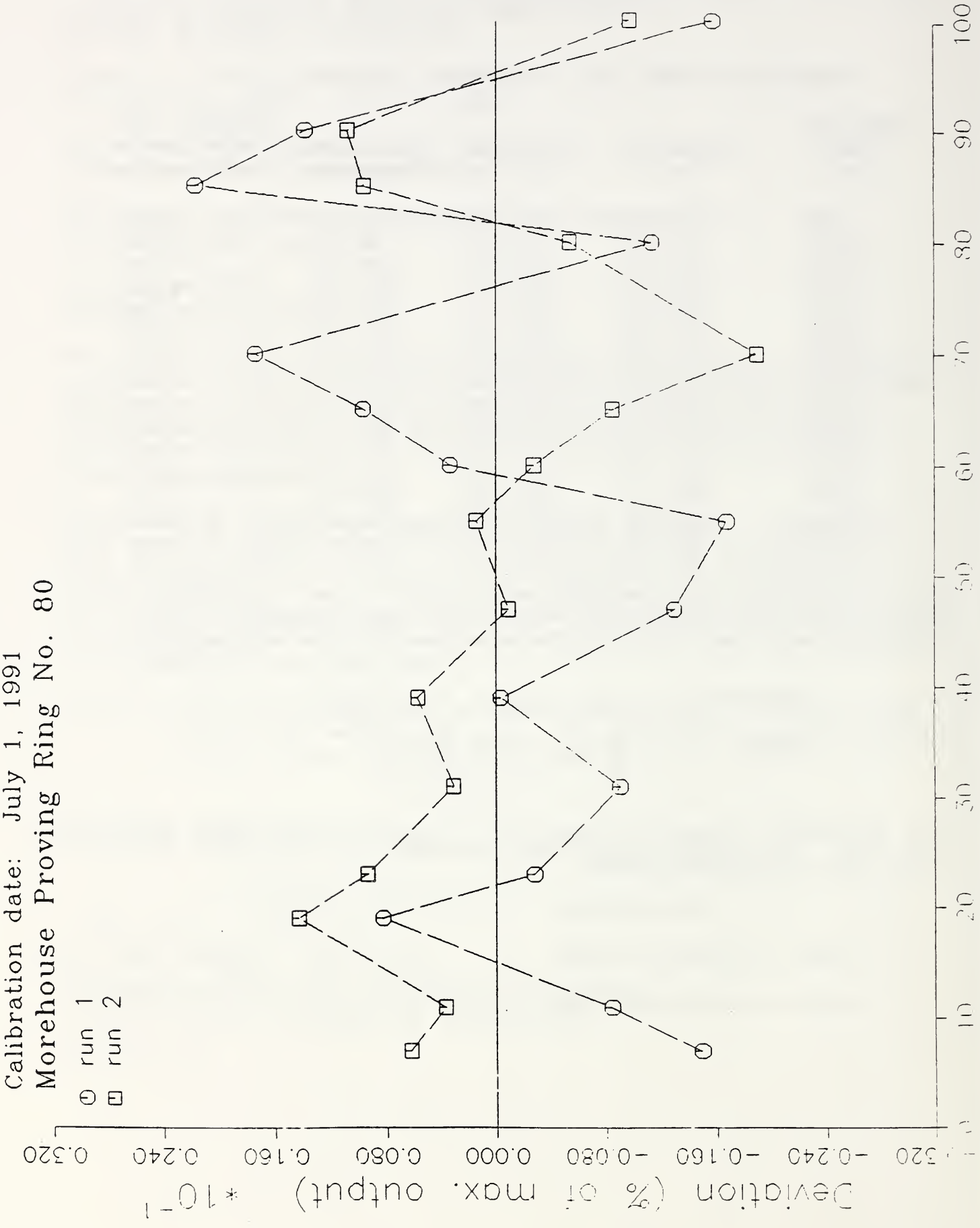
where
A = 9.74419E-02
B = 8.07347E-02
C = 1.76863E-07

The following values, as defined in ASTM E74-83, were determined from the calibration data:

Uncertainty = 2.8 lbf

Class A Loading Range = 1107 to 10000 lbf

Class AA Loading Range = 5536 to 10000 lbf


Calibration date: July 1, 1991
Morehouse Proving Ring No. 80
run 1
run 2
Deviation (% of max. output) *10⁻¹
0.320
0.240
0.160
0.080
0.000
-0.080
-0.160
-0.240
-0.320
10
20
30
40
50
60
70
80
90
100
Compression Load (% of max. load of 10000 lbf)

Calibration Date: July 1, 1991

Morehouse Proving Ring No. 80
Capacity 10000 lbf Compression

Compression Run Deviations

Applied Load (lbf)	Deviation Run 1	Deviation Run 2	Predicted Response
700	-0.12	0.05	56.70
1100	-0.07	0.03	89.12
1900	0.07	0.12	154.13
2300	-0.02	0.08	186.72
3100	-0.07	0.03	252.07
3900	0.00	0.05	317.65
4700	-0.11	-0.01	383.46
5500	-0.14	0.01	449.49
6000	0.03	-0.02	490.87
6500	0.08	-0.07	532.35
7000	0.14	-0.16	573.91
8000	-0.09	-0.04	657.29
8500	0.18	0.08	699.12
9000	0.11	0.09	741.04
10000	-0.13	-0.08	825.13

Appendix B

Micrometer Head Calibration

U. S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

REPORT OF TEST No. 731/G46306-91

For: Boeckeler Instruments Micrometer
NBS Number 179139

Submitted by: T. Robert Shives
NIST Division 855

The micrometer submitted was tested against a high accuracy coordinate measuring machine. The results of the calibration are given in the table below.

Nominal (inch)	Actual (inch)	Correction (inch)
0.00000	0.00000	0.00000
0.10200	0.10201	0.00001
0.20400	0.20401	0.00001
0.30600	0.30600	0.00000
0.40800	0.40799	-0.00001
0.51000	0.50999	-0.00001
0.61200	0.61199	-0.00001
0.71400	0.71399	-0.00001
0.81600	0.81598	-0.00002
0.91800	0.91798	-0.00002
1.0000	0.99998	-0.00002

The test data was corrected to standard conditions (20 °C) using a thermal expansion coefficient of 11.5×10^{-6}/°C. The uncertainty estimated from the repeatability of the data and the accuracy of the machine is 0.00002 in.

Measurements were made by _____.

For the Director,
National Institute for Standards and Technology

Mr. Ralph Veale, Group Leader
Dimensional Metrology Group
Center for Manufacturing Engineering

Order No. 855-4644
Group Control M3882
Date: August 6, 1991

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T. Robert Shives and Richard J. Fields

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[ ] DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

Values of the modulus of elasticity and Poisson's ratio in compression were determined for three samples of type 17-4 PH stainless steel and for one sample of type 410 stainless steel. The three samples of the 17-4 PH were from different locations of one bar of material. The results obtained agree well with values reported in the literature.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

17-4 PH stainless steel; 410 stainless steel; compression testing; modulus of elasticity; Poisson's; stainless steel

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